

ARMY RESEARCH LABORATORY



Vehicle Tire and Wheel Creation in BRL-CAD

by Clifford Yapp

ARL-CR-625

April 2009

prepared by

**Quantum Research International, Inc.
2014 Tollgate Rd., Ste. 203
Bel Air, MD 21015**

under contract

W911QX-06-F-0057

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5068

ARL-CR-625

April 2009

Vehicle Tire and Wheel Creation in BRL-CAD

**Clifford Yapp
Quantum Research International, Inc.**

REPORT DOCUMENTATION PAGE			<i>Form Approved OMB No. 0704-0188</i>		
<p>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>					
1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE		3. DATES COVERED (From - To)		
April 2009	Final		April 2008–June 2008		
4. TITLE AND SUBTITLE			5a. CONTRACT NUMBER W911QX-06-F-0057		
Vehicle Tire and Wheel Creation in BRL-CAD			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S)			5d. PROJECT NUMBER		
Clifford Yapp			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)			8. PERFORMING ORGANIZATION REPORT NUMBER		
Quantum Research International, Inc. 2014 Tollgate Rd., Ste. 203 Bel Air, MD 21015					
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S) ARL		
U.S. Army Research Laboratory ATTN: AMSRD-ARL-SL-BS Aberdeen Proving Ground, MD 21005-5068			11. SPONSOR/MONITOR'S REPORT NUMBER(S) ARL-CR-625		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Vehicle wheels are often approximated in BRL-CAD models with tori, cylinders, or other basic geometric shapes that represent a very rough visual and geometric approximation of a tire/wheel combination. The tire modeling tool written for BRL-CAD provides users with the ability to rapidly generate complex tire and wheel structures with standard dimensional input information.					
15. SUBJECT TERMS BRL-CAD, vehicle, tire, wheel, procedure, CSG					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 26	19a. NAME OF RESPONSIBLE PERSON Michael Gillich
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) 410-278-7820

Contents

List of Figures	iv
List of Tables	v
1. Overview	1
2. Specifying a Tire With Standard Dimensional Conventions	1
3. Options for Tire Tread Modeling	4
4. Setting Tire Thickness	7
5. Changing the Rim Width	9
6. Changing the Radial Location of the Maximum Tire Width	10
7. Other Options	11
8. Structure of a Tire Model	12
9. Summary	13
Distribution List	14

List of Figures

Figure 1. Default tire model created by tire tool	2
Figure 2. Example models generated by use of tire 's dimensional flag.	3
Figure 3. Cutaway views of the default tire model—the left image uses default illumination and the right image uses the surface-normals illumination model.	4
Figure 4. Combination of curved profile and all-weather tread pattern generated with the command tire -p 1	5
Figure 5. Combination of squared-off profile and off-road tread generated with the command tire -p 2	5
Figure 6. Combination of squared-off profile and all-weather tread pattern generated by tire -t 2 -p 1	6
Figure 7. Combination of squared-off profile and off-road tread with increased tread depth generated by tire -p 2 -g 25	6
Figure 8. Combination of curved profile, off-road tread, and increased tread pattern count generated by tire -p 2 -t 1 -c 100	7
Figure 9. External view of a 395/85R20 tire with off-road tread and deepened tread grip.	8
Figure 10. Cross-section views—default and surface normal—of the default thickness on the 395/85R20 tire.	8
Figure 11. Cross-section views—default and surface normal—of the new 395/85R20 tire with increased thickness.	9
Figure 12. Demonstration of tire model changes when different rim widths are used.	10
Figure 13. From left to right, the <i>s</i> flag settings are 260, 270, and 280. Notice in the surface normal view, the change in color gradient on the side walls. In the normal view, notice the different shapes the tires exhibit. The visual impact of this parameter can be fairly subtle.	11
Figure 14. Visualization of air region inside a tire.	12

List of Tables

Table 1. Input format for tire tool	2
Table 2. Valid input strings for tire dimensions.	2
Table 3. Invalid input strings for tire dimensions.	3
Table 4. Available profiles and patterns.	5

INTENTIONALLY LEFT BLANK.

1. Overview

Traditionally, BRL-CAD tire models have been created using a single cylinder, a torus intersected with a cylinder, or in some cases, additional combinations of these primitives. While these approximations are often sufficient for analytical purposes, the resulting model is typically a poor visual match to the real tire when raytracing. Creating more complex models to better approximate the tire's shape almost always requires more resources than can be justified.

The **tire** modeling tool written for BRL-CAD offers a method to generate a model that is dimensionally close to a “real” tire using primitives and constructive solid geometry operations. The primitives used are the elliptical torus (eto), right circular cylinder (rcc), ellipsoid (ell), and truncated general cone (tgc). When tread is added, the sketch and extrude primitives are also used.

By default, a basic steel wheel (i.e., “rim”) is included in the model. If this wheel does not work for a given modeling purpose, it is quite simple to remove it and substitute a user-defined wheel as long as the dimensions of the user-supplied wheel match the standard wheel at the key points (radius and width).

While the **tire** tool can supply tread, it does not do so by default (figure 1). Complex tread patterns can significantly increase the time for analysis and visualization, so the modeler needs to bear this cost in mind. The tire generated is always centered at the global origin.

2. Specifying a Tire With Standard Dimensional Conventions

The default behavior for the tire procedure with no arguments given is to produce a tire of dimensions 215/55R17 without tread in a file named tire.g.

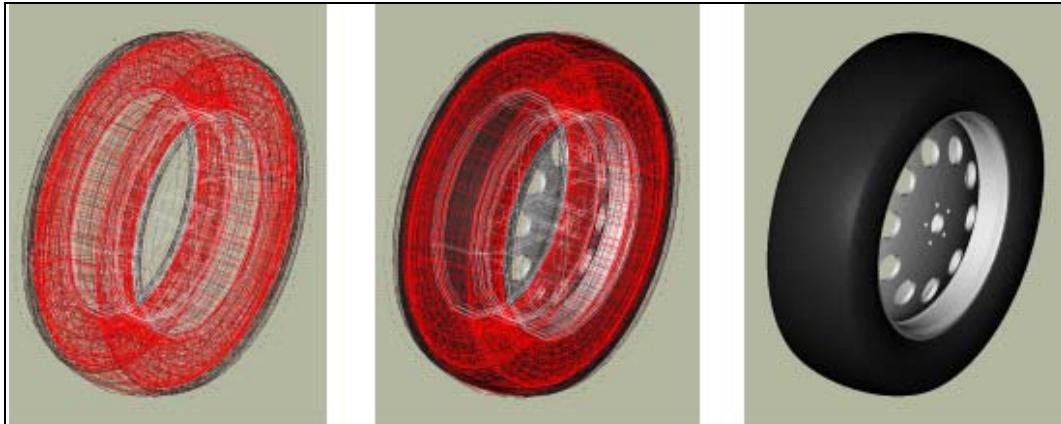


Figure 1. Default tire model created by **tire** tool.

Since this default is unlikely to meet the needs of most specific modeling tasks, almost all uses of **tire** will need the “-d” flag to customize the dimensions:

```
tire -d 255/40R18
```

There are actually a wide variety of standards used in practice to specify tire dimensions. Generally, the majority of them have the same “core” information plus additional performance and rim compatibility notations. At this time, BRL-CAD supports the input format shown in table 1.

Table 1. Input format for **tire** tool.

Width (mm)	Separator	Ratio (#/100)	Separator	Inner Diameter (in)
------------	-----------	---------------	-----------	---------------------

Separators can be any nonnumeric character but are normally either “/” or “-”, or in the case of the latter separator, a letter denoting tire structure. Only single character separators are allowed.* The ratio specifies the sidewall height in terms of the overall tire width, e.g., if a tire is 100 mm wide and the ratio is 40, the sidewall height is 40 mm. Examples of valid input strings are shown in table 2.

Table 2. Valid input strings for tire dimensions.

255/40R18	Width = 255 mm, ratio = 40, wheel diameter = 18 in
250-50R17	Width = 250 mm, ratio = 50, wheel diameter = 17 in
180/100/15	Width = 180 mm, ratio = 100, wheel diameter = 15 in

All three values must be present to have a valid input string. At the moment, this procedure takes only integer arguments and single nonnumeric character separators, so the formatting restrictions need to be observed. Examples of invalid inputs are shown in table 3.

*As yet, BRL-CAD does not use the structural information (e.g., R = radial construction) in the tire building procedure when a valid structure character is supplied, but it may do so in the future; therefore, the “best practice” is to use the letter if available.

Table 3. Invalid input strings for tire dimensions.

255.0/40R18	First number is floating point rather than integer.
250-50RD17	Multiple characters in second separator.
185.65/15	“.” has significance numerically and will not read correctly.

If more precision is needed on any of these inputs, the **tire** tool offers other command-line options to use instead of (or even in combination with) the *d* flag, which accepts floating point input. When used *with* the *d* flag, the following option flags override the value for their particular parameter supplied to the *d* flag. The option flags are *W* for maximum width, *R* for the ratio, and *D* for the diameter of the wheel. For example, if a width of 255.5 mm was needed, the command could be:

```
tire -d 255/40R18 -W 255.5
```

There are limits to the dimensional configurations that can be modeled by **tire** (e.g., hub width cannot be wider than the maximum tire width), but it should cover most real-world dimensions. Some examples are shown in figure 2.

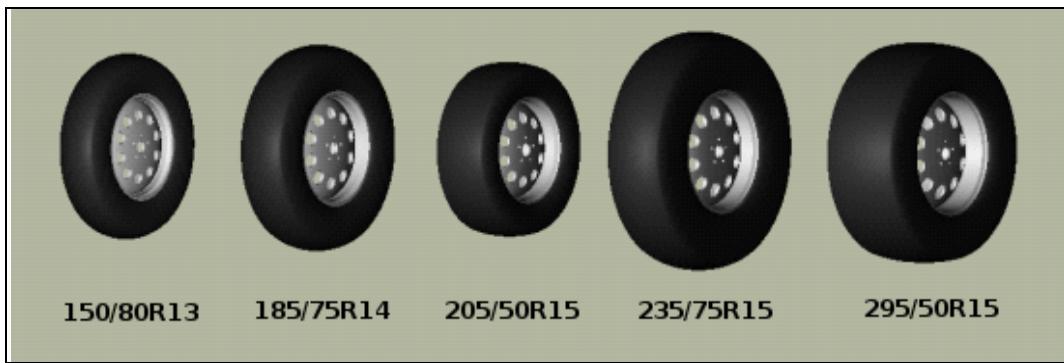


Figure 2. Example models generated by use of **tire**'s dimensional flag.

The model that is created by this routine results in a hollow tire with a thickness (by default) related to its radius—the greater the tire radius, the thicker the tire “walls.” The structure created is a fairly good geometric tire shape, but it does not contain any internal structure within the tire material itself. In reality, modern radial tires are composed of several different layers of varying materials designed to enhance structural strength and performance. As of April 2008, the **tire** tool approximates tire surfaces and walls as being a single region (figure 3).

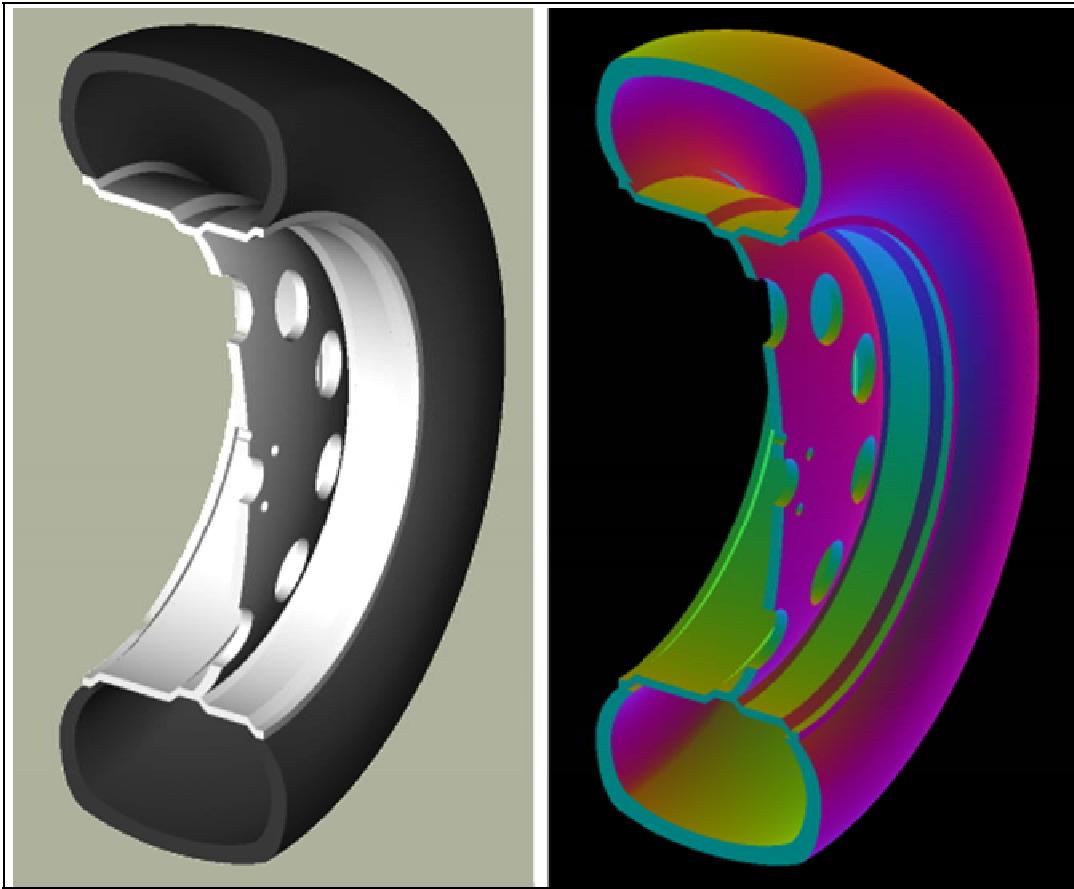


Figure 3. Cutaway views of the default tire model—the left image uses default illumination and the right image uses the surface-normals illumination model.

3. Options for Tire Tread Modeling

Tread is the most difficult part of a tire to define in terms of the amount of input data required. At present, it is not possible for a user to define tread on the command line—only built-in tread options are available.*

Tread profile and tread pattern are the two factors to consider when specifying tread. Tread profile is the “shape” of the tread on the edges of the tread pattern. Many truck tires have a “squared off” tread, while automobile tires tend to have more rounded tread. Different patterns can be combined with different profiles.

The *t* flag controls the tread profile, and the *p* flag controls the tread pattern. The available profiles and patterns are shown in table 4.

*In most cases, BRL-CAD will not have predefined knowledge of specific real-world tread patterns.

Table 4. Available profiles and patterns.

Profile No.	Profile (t)	Pattern No.	Pattern (p)
1	Curved	1	All weather
2	Squared off	2	Off-road

Using either the *t* or *p* flags to the tire command will trigger tread generation. For each flag, a default on the other flag is assumed. If only the *p* flag is specified, the *t* value is assumed to be the same and vice versa. To override the assumption, both flags may be specified. Figure 4 shows the default output for style 1. Style 2 is intended more for trucks and other rugged vehicles (figure 5).

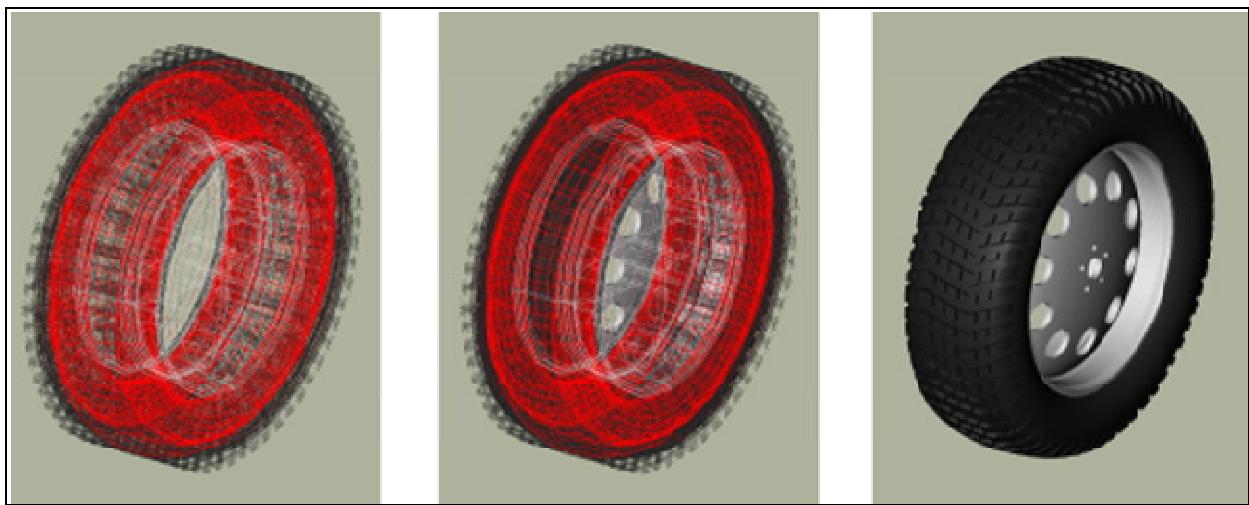


Figure 4. Combination of curved profile and all-weather tread pattern generated with the command **tire -p 1**.

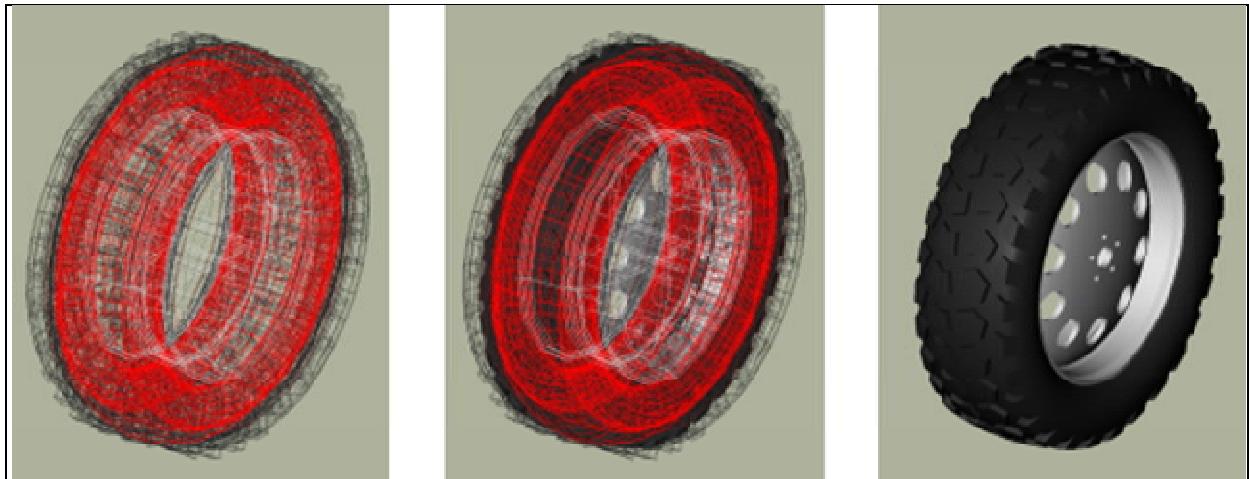


Figure 5. Combination of squared-off profile and off-road tread generated with the command **tire -p 2**.

Using *t* in place of *p* will also produce the same model. Internally, the **tire** command must use some pattern and profile for every tread it creates; for ease of use, it will select a default if a pattern or profile is specified by itself. Using the flags together can produce different results—e.g., profile 2 with pattern 1, as shown in figure 6.

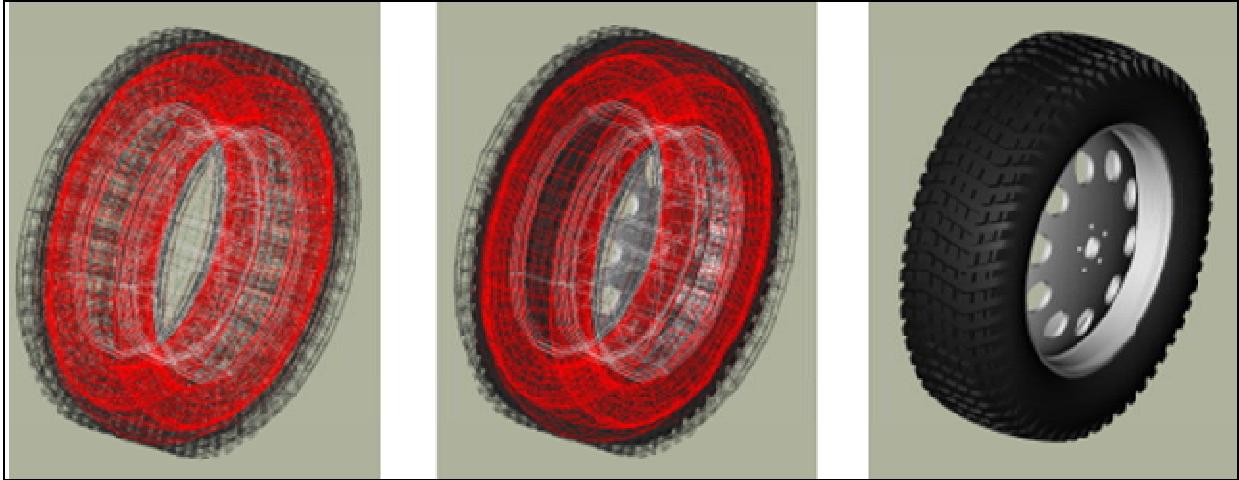


Figure 6. Combination of squared-off profile and all-weather tread pattern generated by **tire -t 2 -p 1**.

Two additional user-level flags exist that can change the behavior of the tread routine. The first is the *g* flag, which can be used to specify different tread depths in integer numbers of 32nds of an inch. For example, the default no. 2 style can be rendered to produce a different look with a deeper tread (figure 7).

```
tire -p 2 -g 25
```

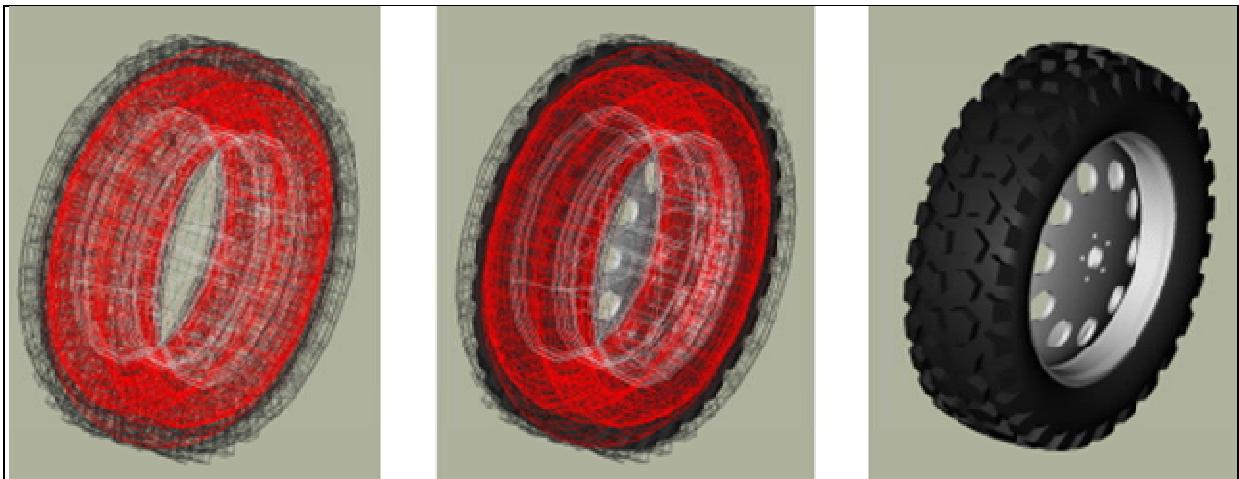


Figure 7. Combination of squared-off profile and off-road tread with increased tread depth generated by **tire -p 2 -g 25**.

The other flag is the *c* flag, which allows user control over how many copies of the master tread pattern are used to encircle the tread surface of the tire. This can be used to create courser or finer tread with the same geometric pattern. For example, if the first profile, second pattern, and a count of 100 are used, they produce the model shown in figure 8.

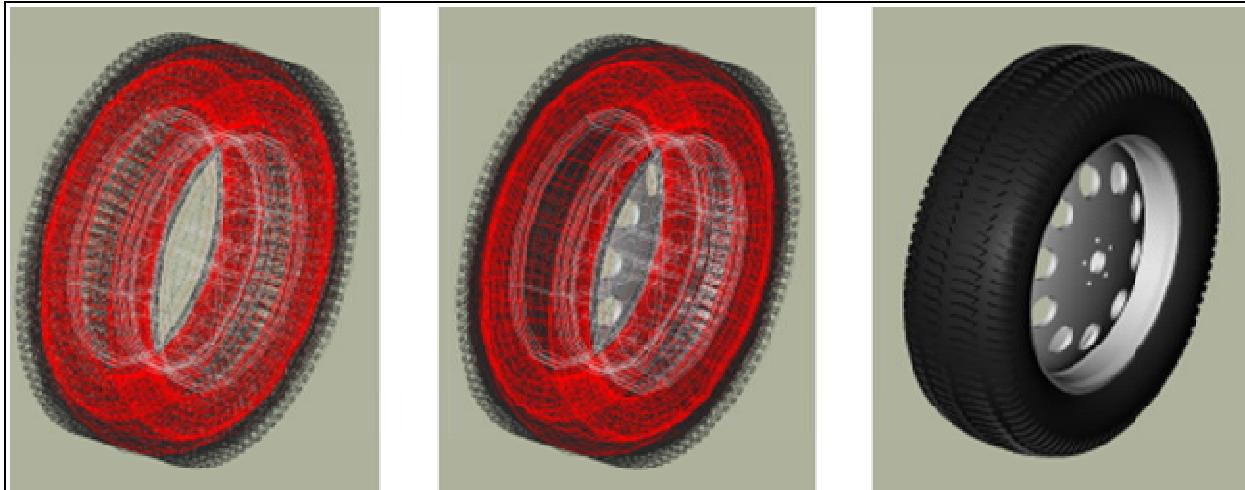


Figure 8. Combination of curved profile, off-road tread, and increased tread pattern count generated by **tire -p 2 -t 1 -c 100**.

Adjusting the count of patterns can be a way to get a different visual tread style without defining a new tread pattern, although it is unlikely to result in a “real” pattern in the sense of representing an in-use tire tread.

Note: When using the count flag, it is important to remember that tread patterns are actual geometry, and a high count of patterns can slow down a raytrace considerably. A strategy for models that will have a variety of uses is to include both treaded and slick (nontreaded) tire models in the database under different names, make a tire-model.c combination that is referenced by the vehicle model, and include either the treaded or nontreaded model in the tire-model.c combination based on the analysis.

4. Setting Tire Thickness

Tire thickness is manipulated via the *u* flag. By default, the tire procedure will adjust the thickness of the tire according to the size of the tire, but there may be cases where it is desirable to change this thickness.

Let's say a model of a large vehicle tire is needed, and it is known that a very thick wall is being used (figure 9). To start, input the dimensional information:

```
tire -d 395/85R20 -p 2 -g 30
```



Figure 9. External view of a 395/85R20 tire with off-road tread and deepened tread grip.

Now, examine figure 10 with the cross section in normal and surface normal views (the tread pattern and depth are added so the cross section with tread is shown—it will change with and without tread).

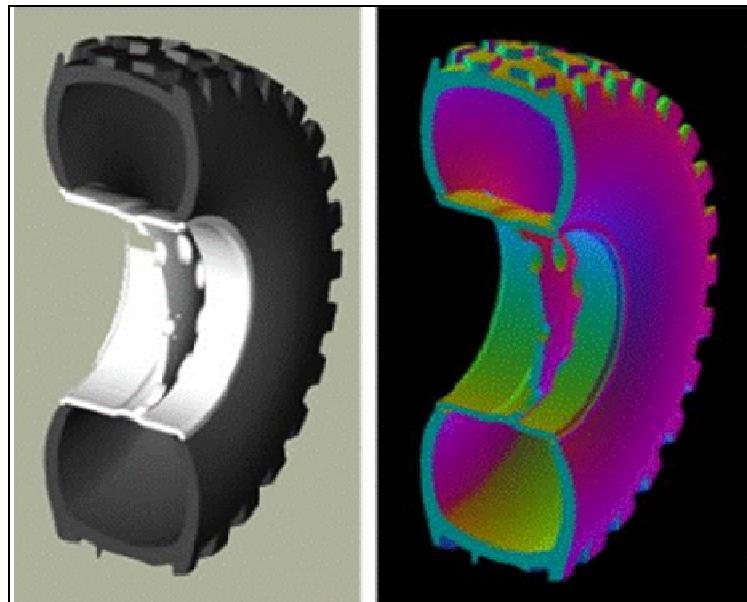


Figure 10. Cross-section views—default and surface normal—of the default thickness on the 395/85R20 tire.

This is a visual check—other tools are available for actual dimensional testing. Let's say the desired thickness is 70 mm. The tire regenerated is thus:

```
tire -d 395/85R20 -p 2 -g 30 -u 70
```

Examining the cross sections again, the thickness increase is clearly seen in figure 11.

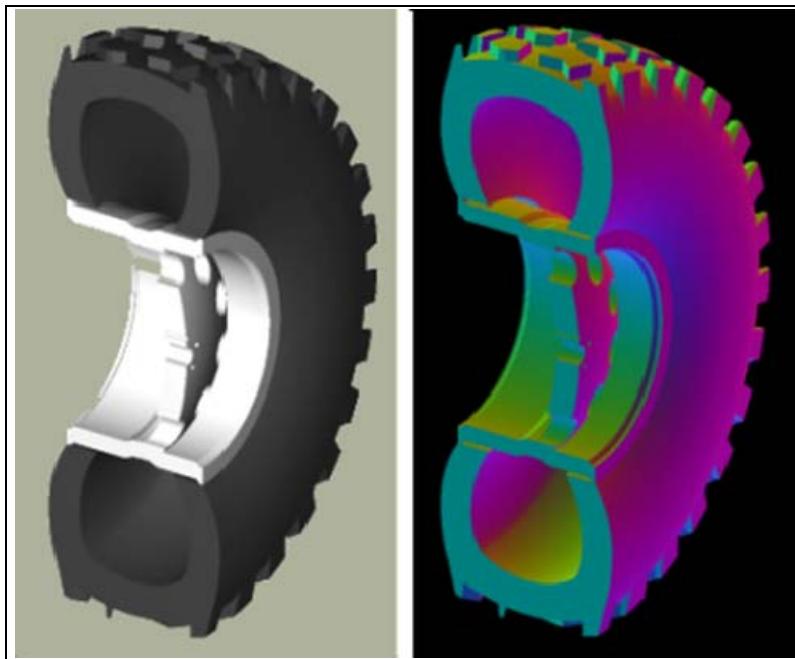


Figure 11. Cross-section views—default and surface normal—of the new 395/85R20 tire with increased thickness.

5. Changing the Rim Width

The default behavior of **tire** is to make the rim width (the width of the tire at the point where the outer wall connects with the steel wheel) equal to the width of the tread, which is, in turn, defined internally as a fraction of the total width. This normally produces reasonable tires, but **tire** does provide the *j* flag to allow custom values for rim width (figure 12). The input units are in inches.

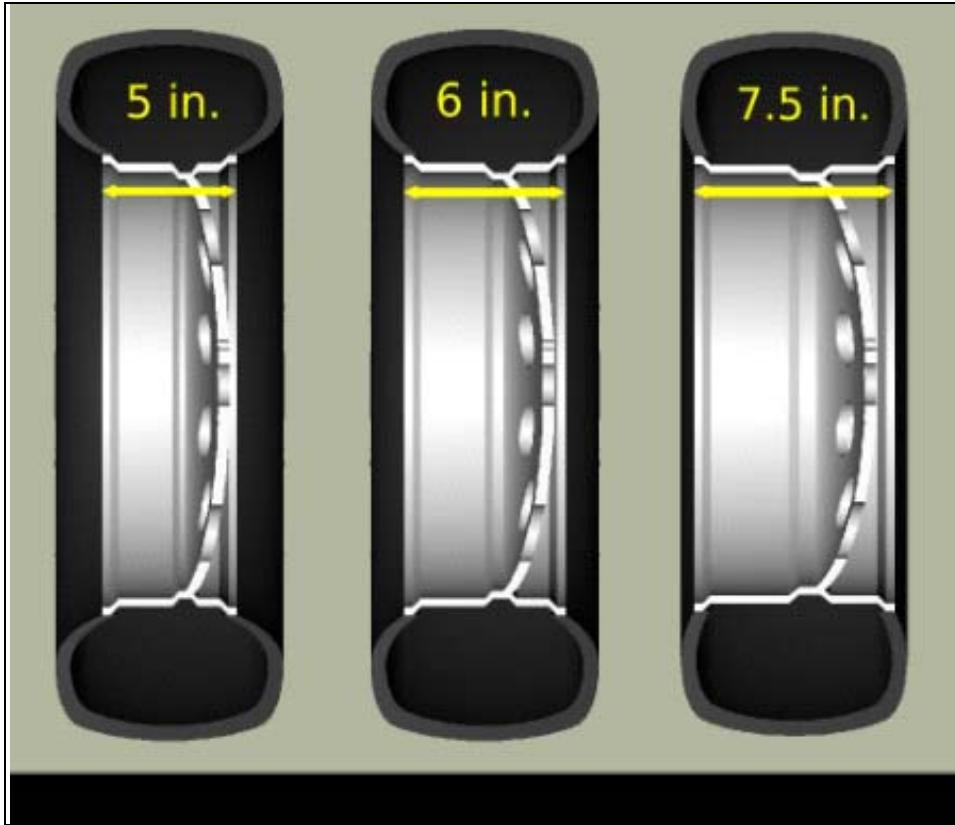


Figure 12. Demonstration of tire model changes when different rim widths are used.

6. Changing the Radial Location of the Maximum Tire Width

When `tire` accepts a maximum width specification, it internally decides on a default distance from the tire center where that maximum will occur. This parameter can be adjusted by the modeler with the `s` flag. Some examples using the narrow rim width model settings from the previous section are shown in figure 13.

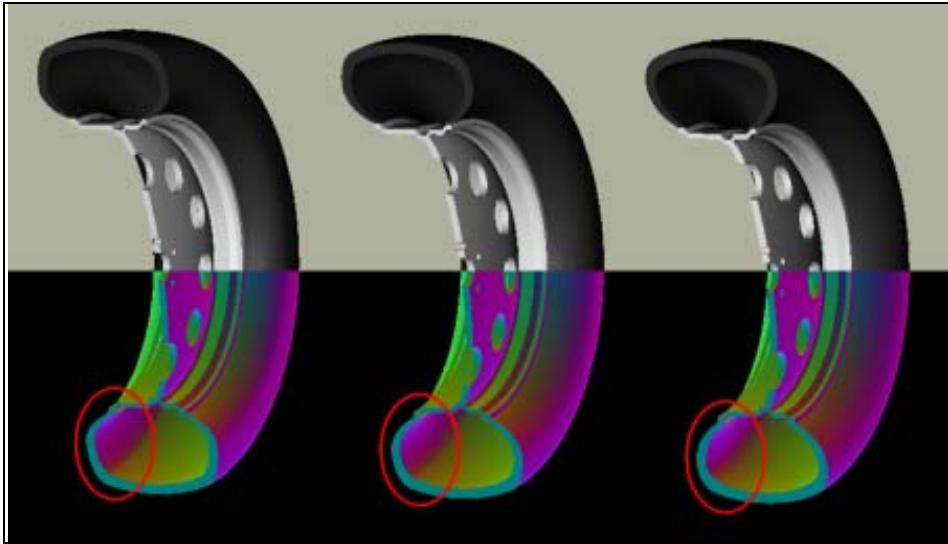


Figure 13. From left to right, the *s* flag settings are 260, 270, and 280. Notice in the surface normal view, the change in color gradient on the side walls. In the normal view, notice the different shapes the tires exhibit. The visual impact of this parameter can be fairly subtle.

7. Other Options

The other flags available in **tire** relate to naming the top-level tire object. The *a* flag automatically appends the dimensional information to the name, making it simple to import multiple tires of different dimensions into a single .g file with the MGED **dbconcat** command. The *n* option allows the modeler to specify a string other than “tire” for the root name of the top-level object. These options can work individually or in concert. So, for example, to generate a top-level name of “car-255-55R17” instead of “tire” for the top-level object, the following will work:

```
tire -a -n "car"
```

By default, the procedure creates a file called “tire.g” to contain the model. If some other name is desired, a different file name can be supplied as the final argument to the tire procedure. For example,

```
tire mytire.g
```

will create the “mytire.g” file and insert the default tire model.

8. Structure of a Tire Model

Although it is not visible to the eye in normal raytracing, the tire models do include knowledge in the model of the presence of air inside the tire as well as the tire and wheel structures themselves. For illustration purposes, figure 14 displays the air region inside the tire.



Figure 14. Visualization of air region inside a tire.

The three material regions are defined immediately below the top-level object:

```
mged> l tire
tire: --
  u tire-215-55R17.r
  u air-215-55R17.r
  u wheel-215-55R17.r
```

The names of these regions will change with the dimensions of the tire requested, but the basic form will remain consistent. The tire-215-55R17.r region holds the tire and tread (if tread was requested), wheel-215-55R17.r holds the rim and internal hub of the wheel, and air-215-55R17.r defines a volume inside the tire and wheel not occupied by the other regions.

```
mged> tree -d 2 tire
tire/
  u tire-215-55R17.r/R
    u tire-solid-215-55R17.c/
      - tire-cut-215-55R17.c/
  u air-215-55R17.r/R
    u wheel-air-215-55R17.c/
      u tire-cut-215-55R17.c/
  u wheel-215-55R17.r/R
    u Inner-Hub-215-55R17.c/
    u Wheel-Rim-215-55R17.c/
```

Below this level, the structure describes the details of cuts and combination interactions needed to specify the tire shape.

Note: Due to the nature of the primitives used to define these shapes, operations such as scaling along one axis may produce unexpected results. Generally speaking, it is almost always easier and less error-prone to regenerate a tire model with different parameters than it is to edit the tire structure directly. The wheel region is fairly simple to remove and work with, but the tire/tread geometries are *much* more involved.

9. Summary

- **tire** is a procedural geometry database tool to create sophisticated tire models using standard dimensional specifications.
- The model consists of three regions which define air, tire, and wheel structures.
- The wheel is generated in response to the tire dimensions, and there is currently only one wheel type available in this procedure. (Users may model and substitute their own wheel designs.)
- Due to performance considerations, tread is not modeled by default but can be added using options.
- Fine-grained control of parameters such as tire thickness is available with optional user flags.

NO. OF
COPIES ORGANIZATION

1 DEFENSE TECHNICAL
(PDF INFORMATION CTR
only) DTIC OCA
8725 JOHN J KINGMAN RD
STE 0944
FORT BELVOIR VA 22060-6218

1 DIRECTOR
US ARMY RESEARCH LAB
IMNE ALC HRR
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 DIRECTOR
US ARMY RESEARCH LAB
AMSRD ARL CI OK TL
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 DIRECTOR
US ARMY RESEARCH LAB
AMSRD ARL CI OK PE
2800 POWDER MILL RD
ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

1 DIR USARL
AMSRD ARL CI OK TP (BLDG 4600)

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>	<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
1 (CD only)	ASST SECY ARMY ACQSTN LOGISTICS & TECH SAAL ZP RM 2E661 103 ARMY PENTAGON WASHINGTON DC 20310-0103	2	NVL SURFC WARFARE CTR DAHLGREN D DICKINSON G24 6138 NORC AVE STE 313 DAHLGREN VA 22448-5157
1 (CD only)	ASST SECY ARMY ACQSTN LOGISTICS & TECH SAAL ZS RM 3E448 103 ARMY PENTAGON WASHINGTON DC 20310-0103	1	AFRL MUNITIONS DIRCTRT N GAGNON 101 W EGLIN BLVD STE 309 EGLIN AFB FL 32542
1 (CD only)	DIRECTOR FORCE DEV DAPR FDZ RM 3A522 460 ARMY PENTAGON WASHINGTON DC 20310-0460	1	AFRL RWAL S STANDLEY 101 W EGLIN BLVD STE 307 EGLIN AFB FL 32542
1	US ARMY TRADOC ANL CTR ATRC W A KEINTZ WSMR NM 88002-5502	1	ASC ENDA VULNERABILITY TEAM T STALEY 1970 MONAHAN WAY BLDG 11A RM 018V WRIGHT PATTERSON AFB OH 45433-7210
1	USARL AMSRD ARL SL E R FLORES WSMR NM 88002-5513		<u>ABERDEEN PROVING GROUND</u>
2	SURVICE ENGRG J DUVALL 4695 MILLENNIUM DR BELCAMP MD 21017-1505	1	US ARMY DEV TEST COM CSTE DTC TT T 314 LONGS CORNER RD APG MD 21005-5055
4	QUANTUM RSRCH INTRNTL M JERNIGAN 2014 TOLLGATE RD STE 203 BEL AIR MD 21015	1	US ARMY EVALUATION CTR CSTE AEC SVE R LAUGHMAN 4120 SUSQUEHANNA AVE APG MD 21005-3013
2	APPLIED RSRCH ASSOC A ROSS 4690 MILLENNIUM DR STE 210 BELCAMP MD 21017-1505	36	DIR USARL AMSRD ARL SL J BEILFUSS J FEENEY J FRANZ M STARKS P TANENBAUM AMSRD ARL SL B G MANNIX AMSRD ARL SL BA D FARENWALD (5 CPS) A VOGT (5 CPS)
2	MANTECH SRS TECHLGY T BROWDER 1984 LEWIS TURNER BLVD FORT WALTON BEACH FL 32547		

NO. OF
COPIES ORGANIZATION

AMSRD ARL SL BD
R GROTE (2 CPS)
AMSRD ARL SL BE
M PERRY (2 CPS)
AMSRD ARL SL BG
P MERGLER (3 CPS)
AMSRD ARL SL BS
S SNEAD (10 CPS)
AMSRD ARL SL BW
L ROACH (3 CPS)

NO. OF
COPIES ORGANIZATION

2 NO PRINS MAURITS LAB
S PRONK
W BOKKERS
PO BOX 45
2280 AA RIJSWIJK ZH
THE NETHERLANDS

1 INDUSTRIEANLAGEN
BETRIEBSGESELLSCHAFT MBH IABG
D ROSSBERG
EINSTEINSTRASSE 20
85521 OTTOBRUNN
GERMANY

INTENTIONALLY LEFT BLANK.